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Ukrainczyk

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(54) HIGH POWER EXPANDED BEAM CONNECTOR AND METHODS FOR USING AND MAKING THE HIGH POWER EXPANDED BEAM CONNECTOR

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(51) **Int. Cl.**^{7} **G02B 6/38**
(52) **U.S. Cl.** **385/70**
(58) **Field of Search** 385/70, 58, 55, 385/33

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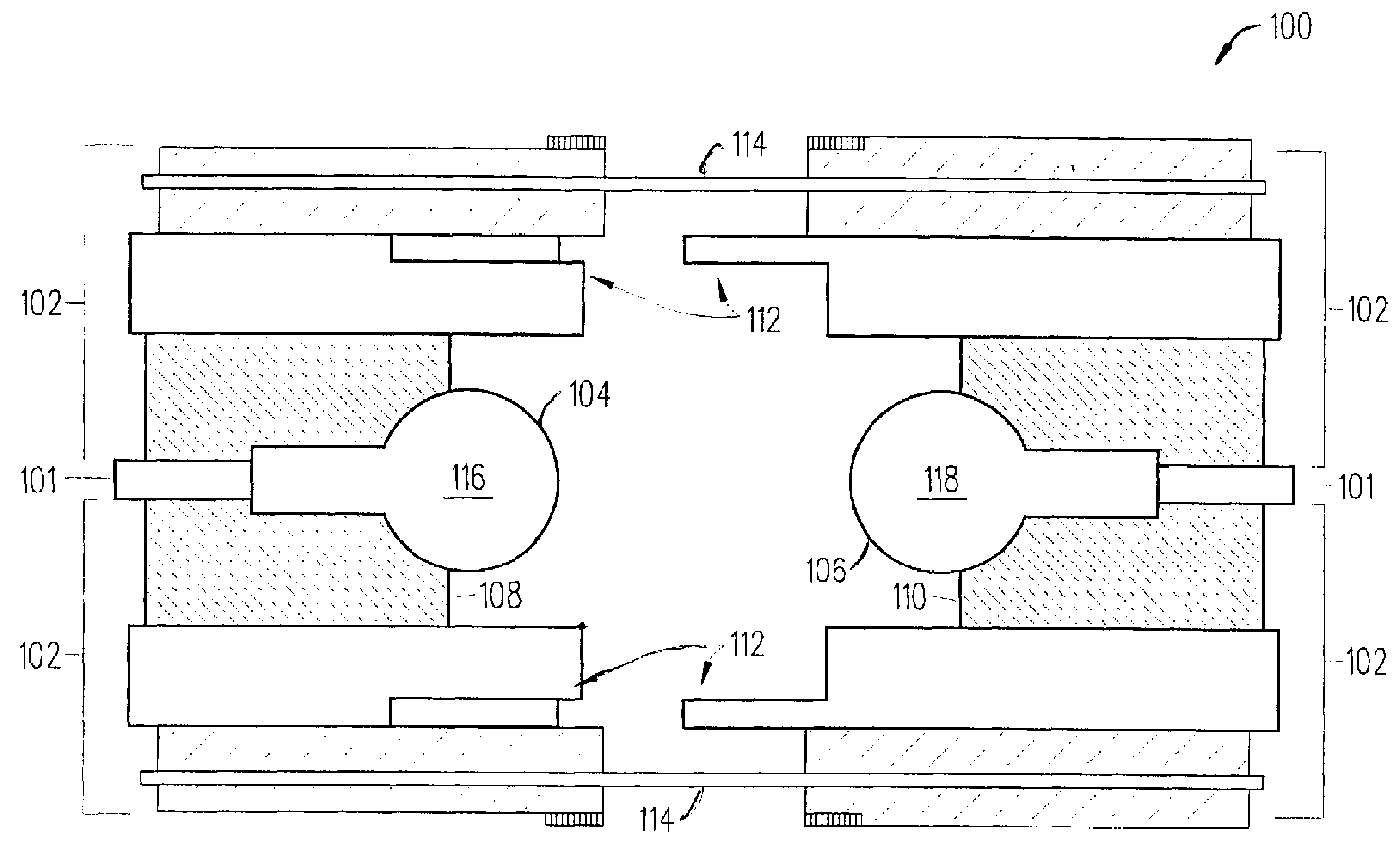
(74) *Attorney, Agent, or Firm*—Timothy M. Schaeberle; William J. Tucker

(57) **ABSTRACT**

A high power expanded beam and methods for making and using the high power expanded beam connector are described herein. Basically, the high power expanded beam connector includes a first lensed optical fiber that is optically coupled to a second lensed optical fiber but physically separated from the second lensed optical fiber. The first lensed optical fiber is capable of expanding a light beam traveling therein and outputting a collimated light beam. The second lensed optical fiber is capable of receiving the collimated light beam and focusing the received light beam such that the light beam travels from the first lensed optical fiber to the second lensed optical fiber. In a similar manner, the high power expanded beam connector can transmit a light beam from the second lensed optical fiber to the first lensed optical fiber.

25 Claims, 7 Drawing Sheets



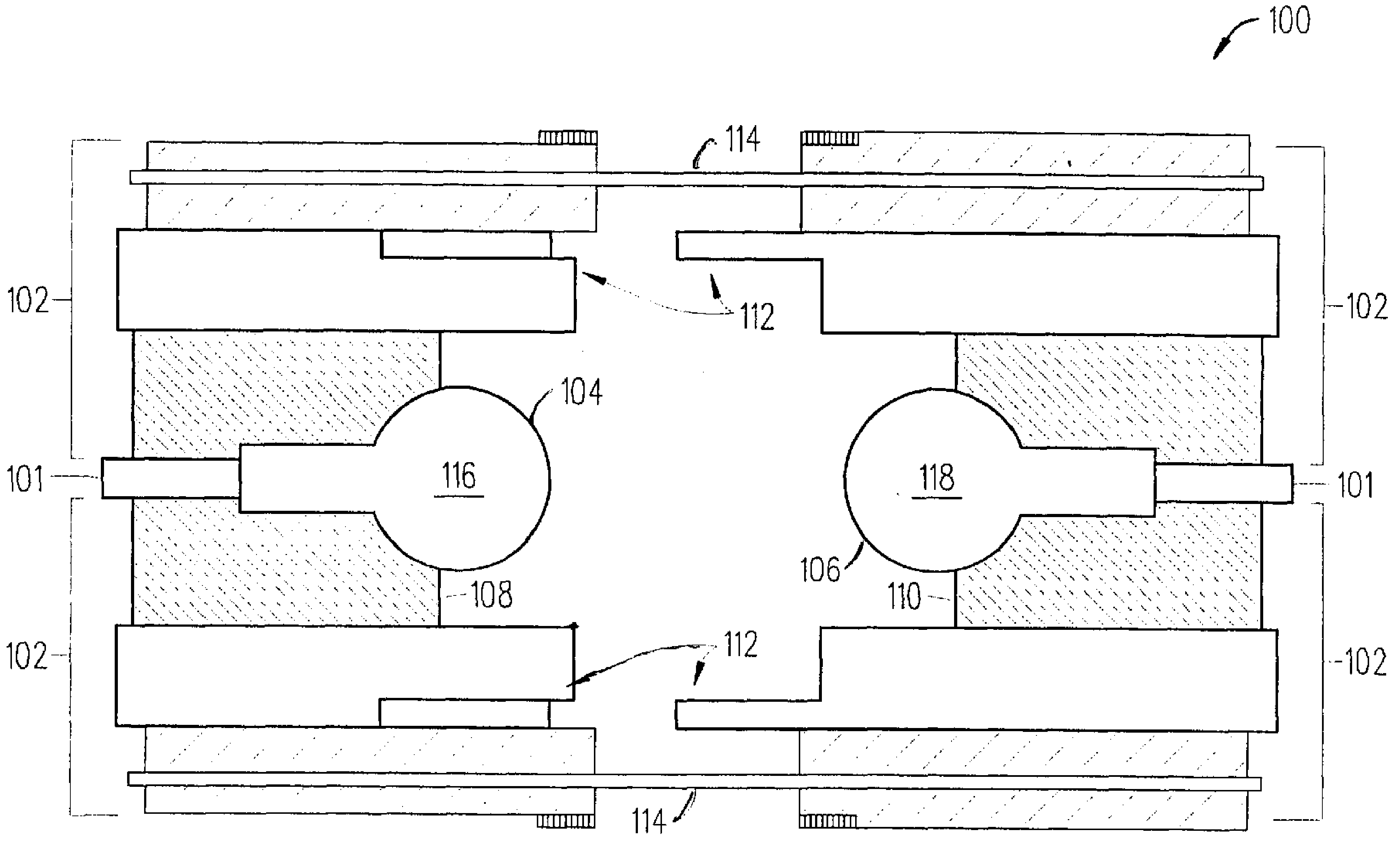

100
114
102
112
102
104
116
118
101
101
106
108
110
102
112
102
114

FIG. 1

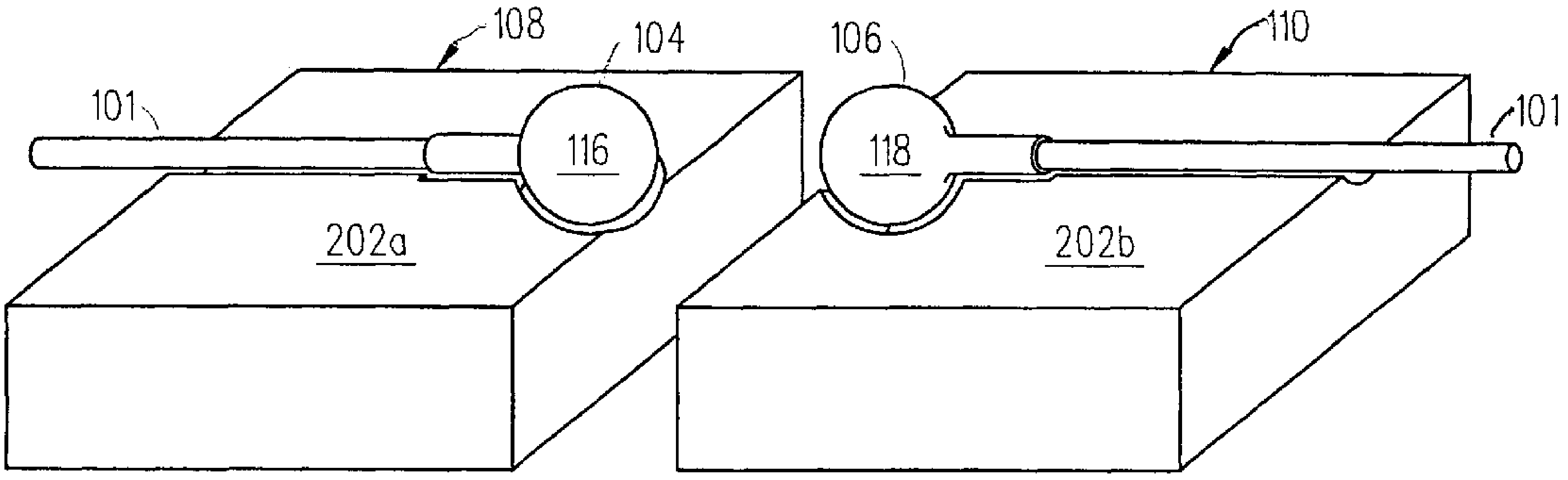

108
104
106
110
101
116
118
101
202a
202b

FIG. 2

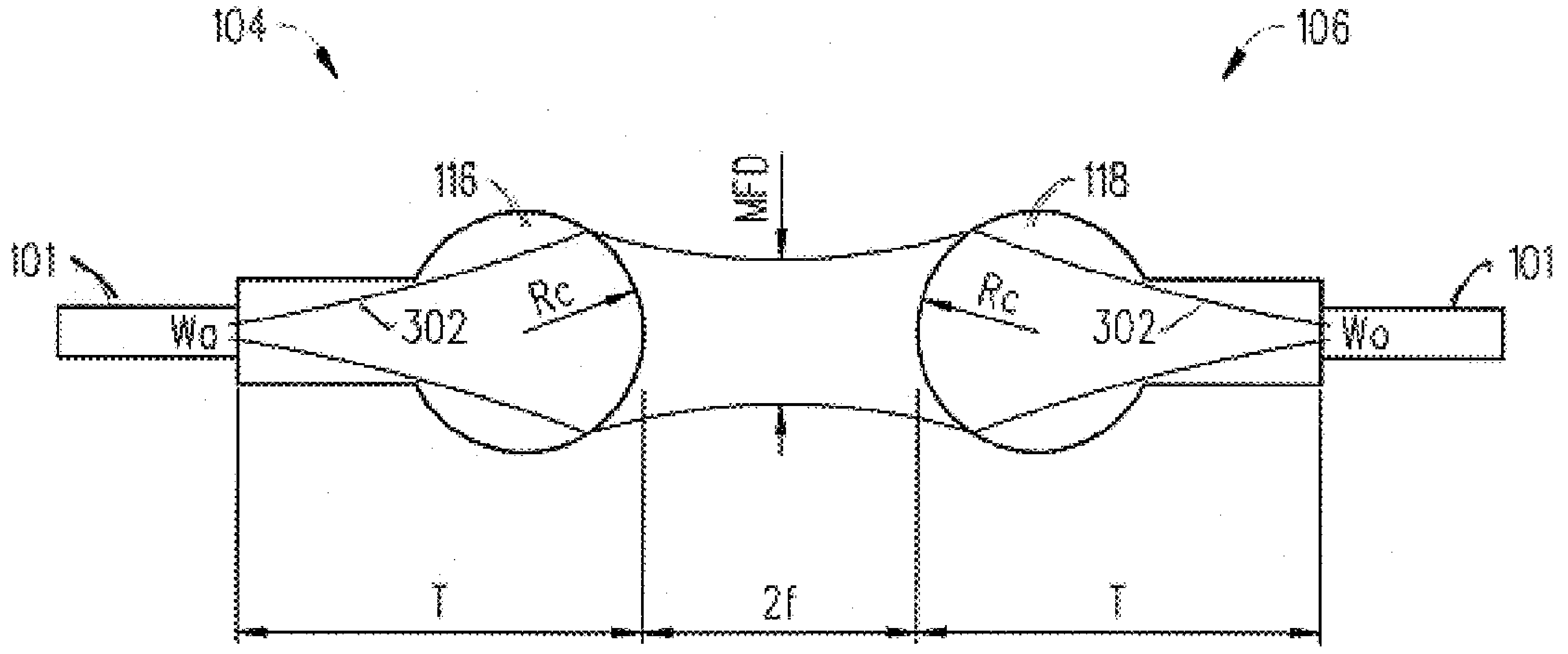

104
106
116
MFD
118
101
101
Wo
302
Rc
Rc
302
Wo
T
2f
T

FIG. 3

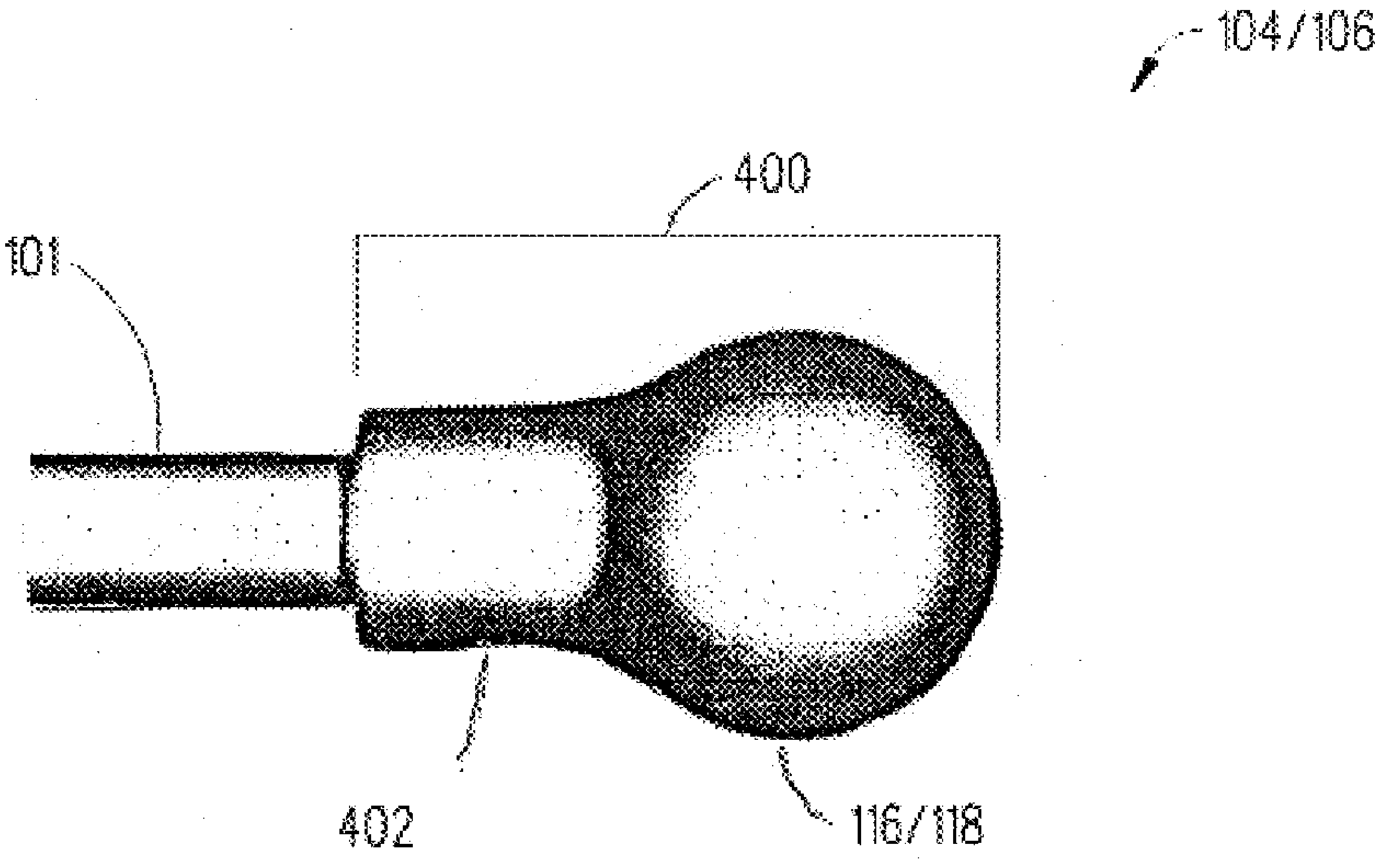

104/106
400
101
402
116/118

FIG. 4

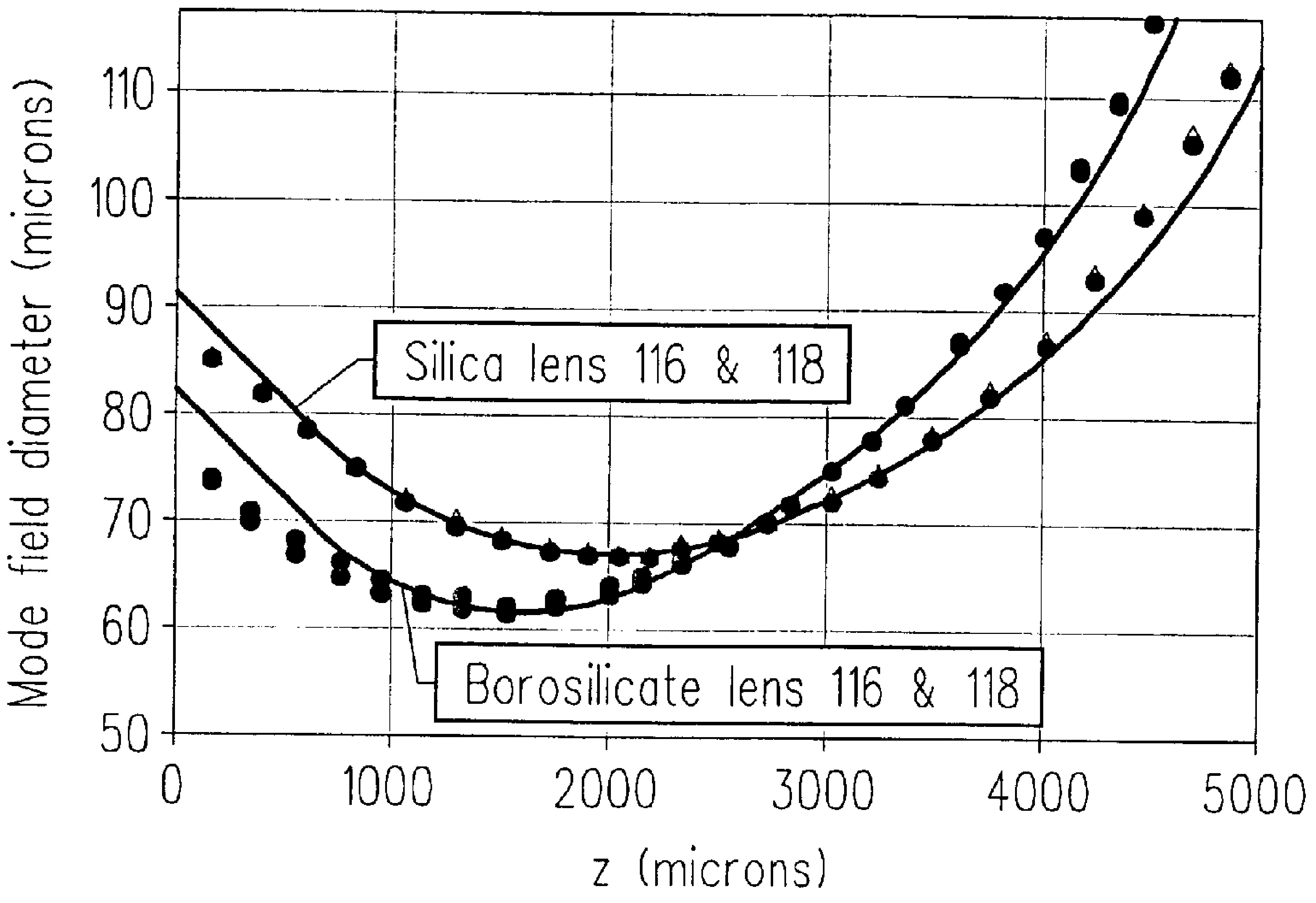

Mode field diameter (microns)
110
100
90
80
70
60
50
0
1000
2000
3000
4000
5000
z (microns)
Silica lens 116 & 118
Borosilicate lens 116 & 118

FIG. 5

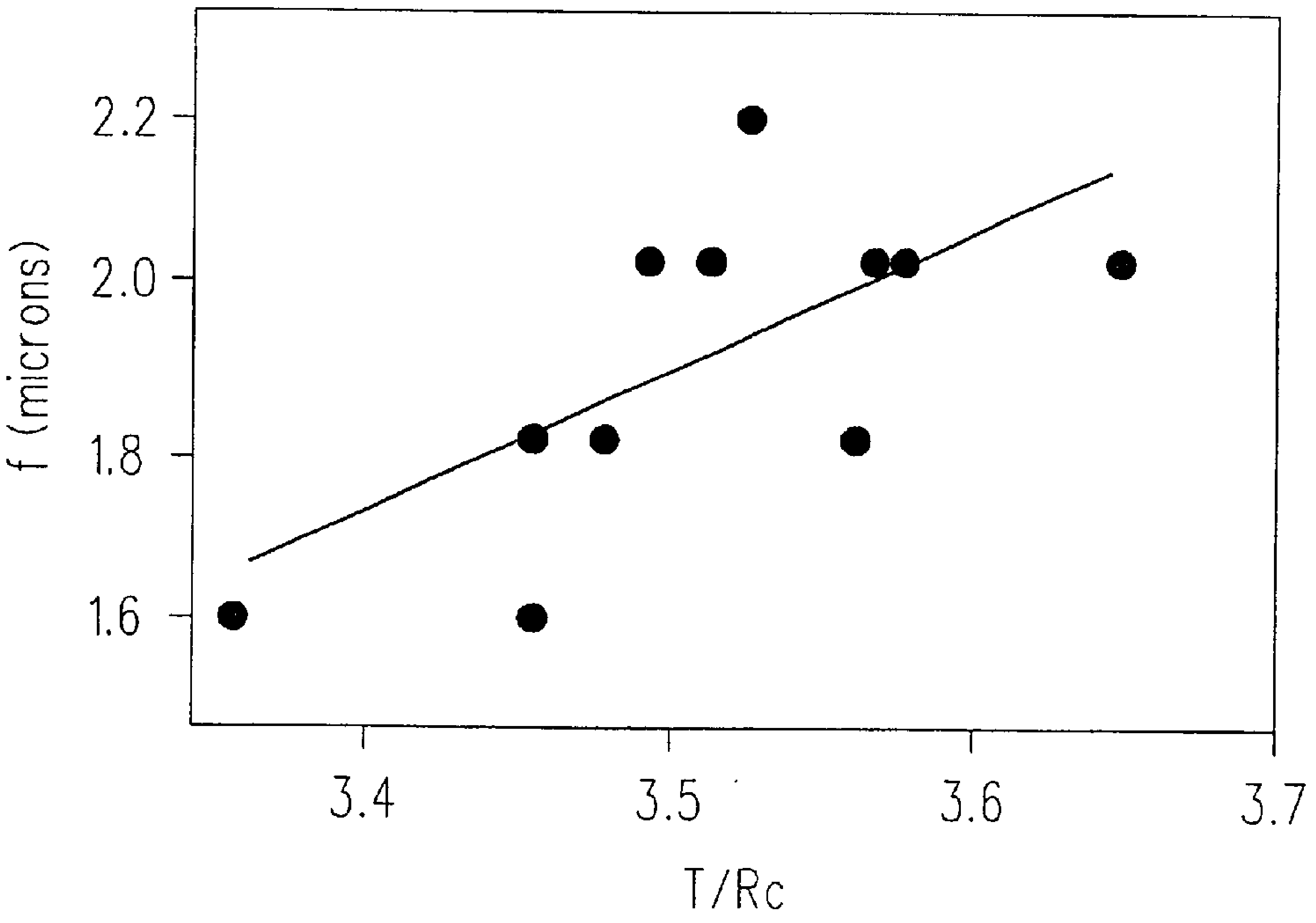

f (microns)
2.2
2.0
1.8
1.6
3.4
3.5
3.6
3.7
T/Rc

FIG. 6A

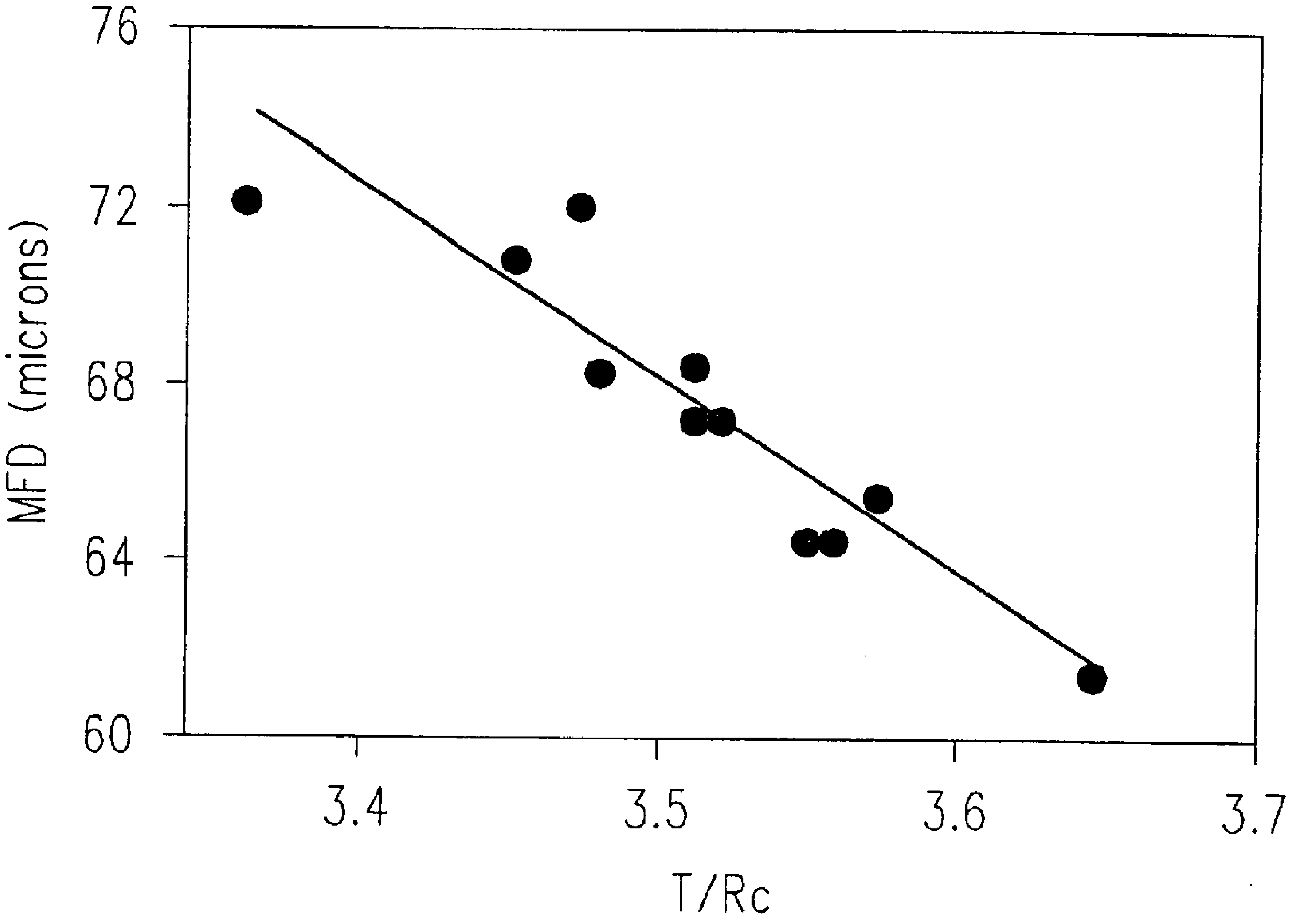

76
72
68
64
60
MFD (microns)
3.4
3.5
3.6
3.7
T/Rc

FIG. 6B

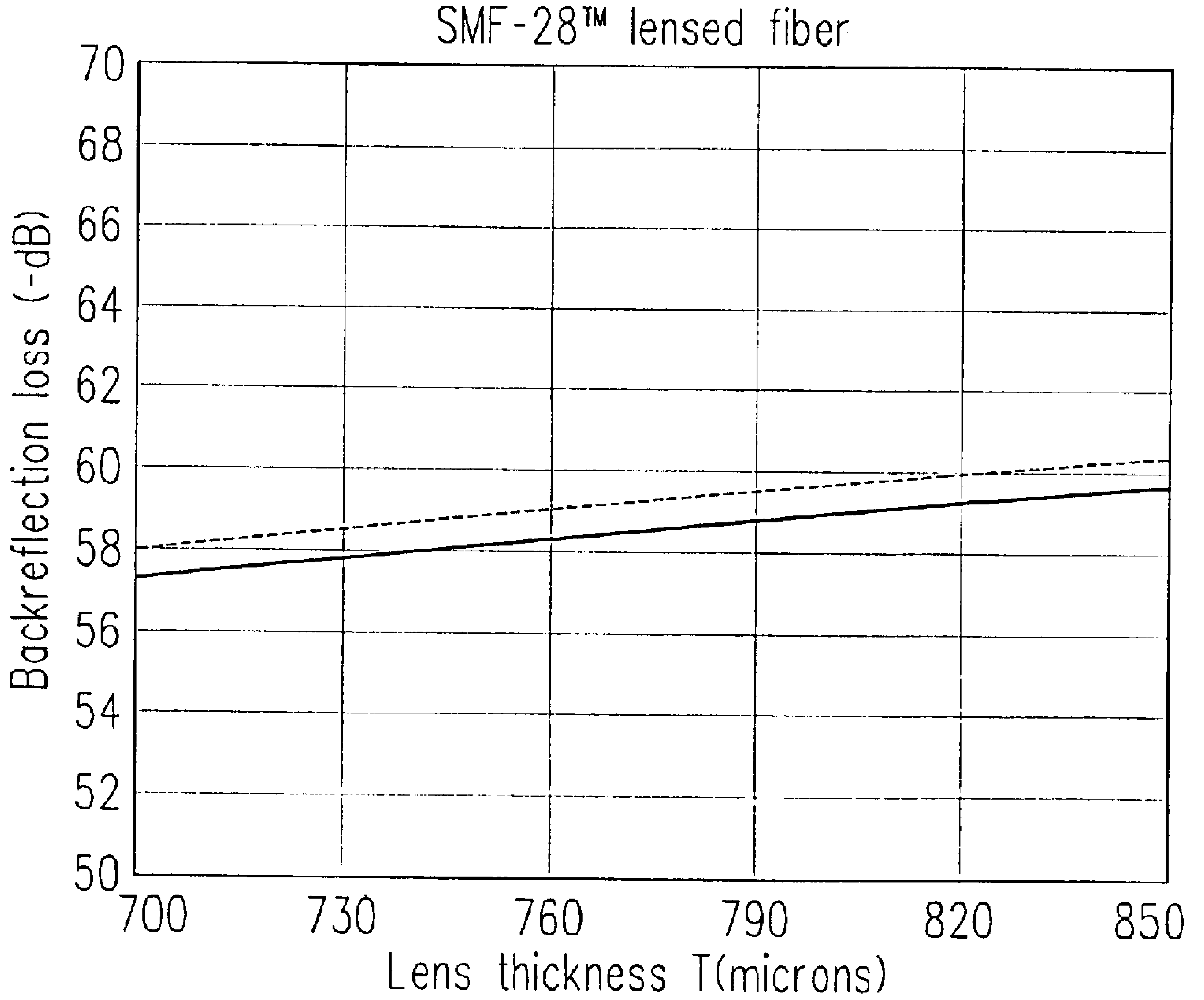

SMF-28™ lensed fiber
70
68
66
64
62
60
58
56
54
52
50
Backreflection loss (-dB)
700
730
760
790
820
850
Lens thickness T(microns)
Rc=227,R=0.25%
Rc=215,R=0.25%

FIG. 7

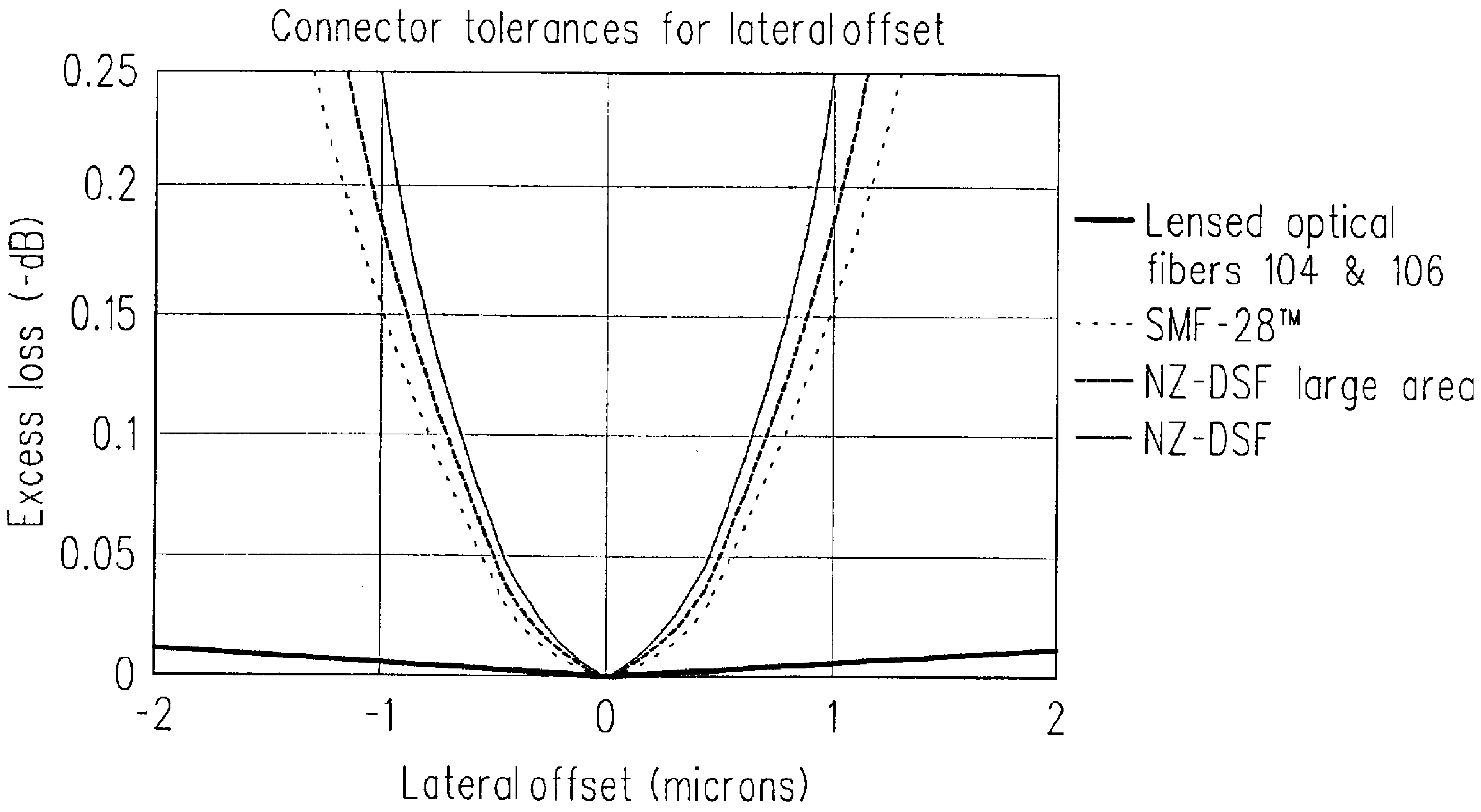

Connector tolerances for lateral offset
Excess loss (-dB)
0.25
0.2
0.15
0.1
0.05
0
-2
-1
0
1
2
Lateral offset (microns)
Lensed optical fibers 104 & 106
SMF-28™
NZ-DSF large area
NZ-DSF

FIG. 8A

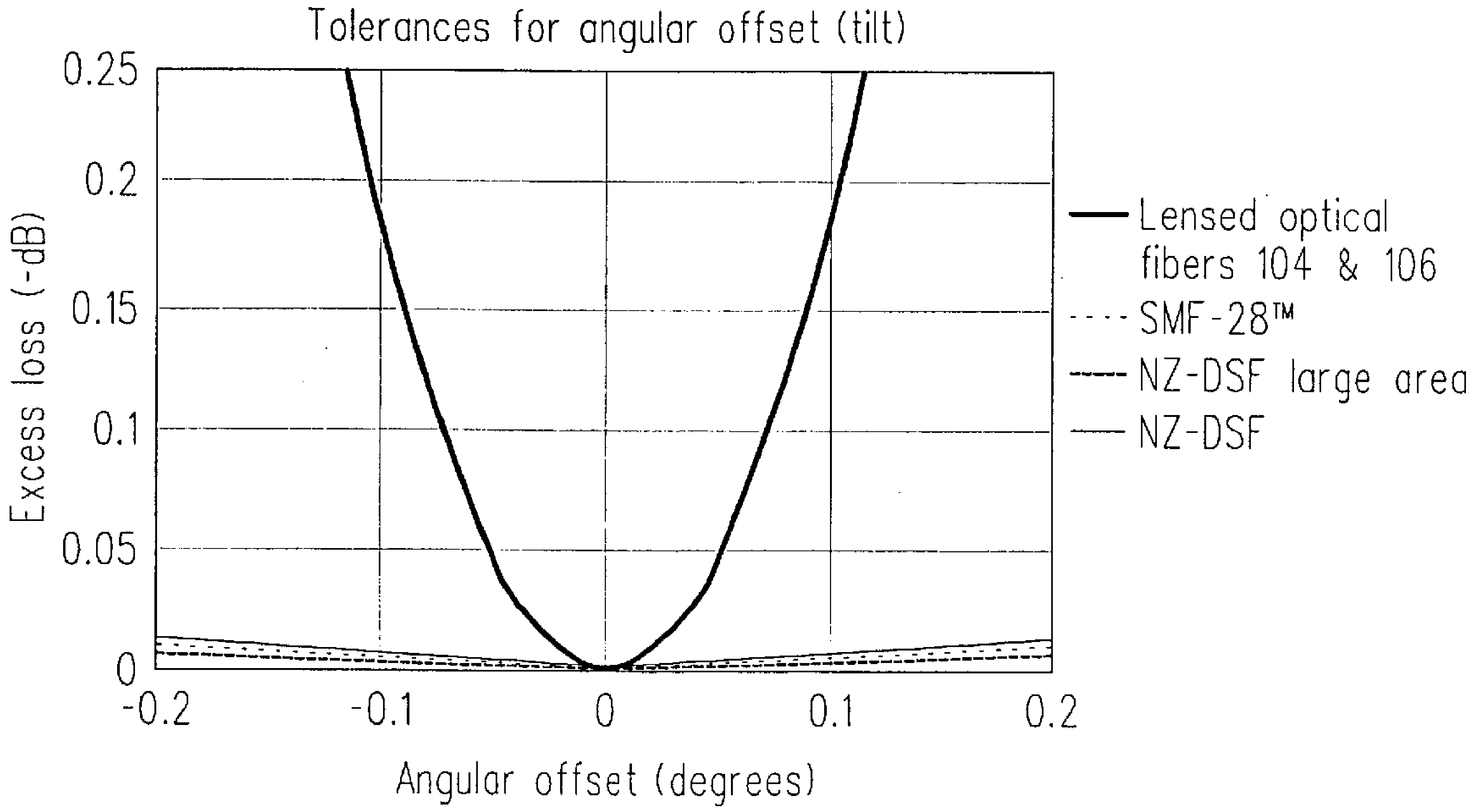

Tolerances for angular offset (tilt)
Excess loss (-dB)
0.25
0.2
0.15
0.1
0.05
0
-0.2
-0.1
0
0.1
0.2
Angular offset (degrees)
Lensed optical fibers 104 & 106
SMF-28™
NZ-DSF large area
NZ-DSF

FIG. 8B

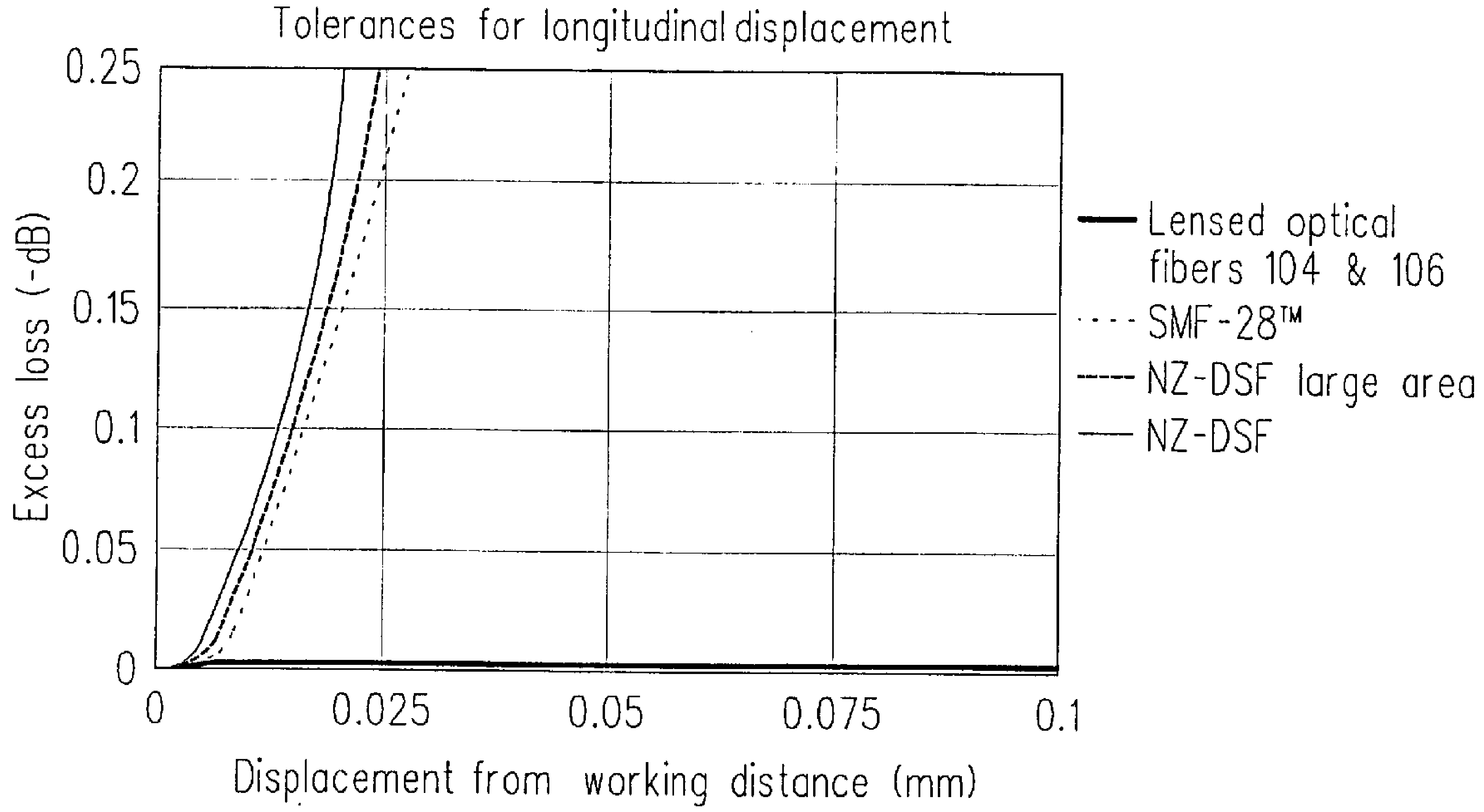

Tolerances for longitudinal displacement
0.25
0.2
0.15
0.1
0.05
0
Excess loss (-dB)
0
0.025
0.05
0.075
0.1
Displacement from working distance (mm)
Lensed optical fibers 104 & 106
SMF-28™
NZ-DSF large area
NZ-DSF

FIG. 8C

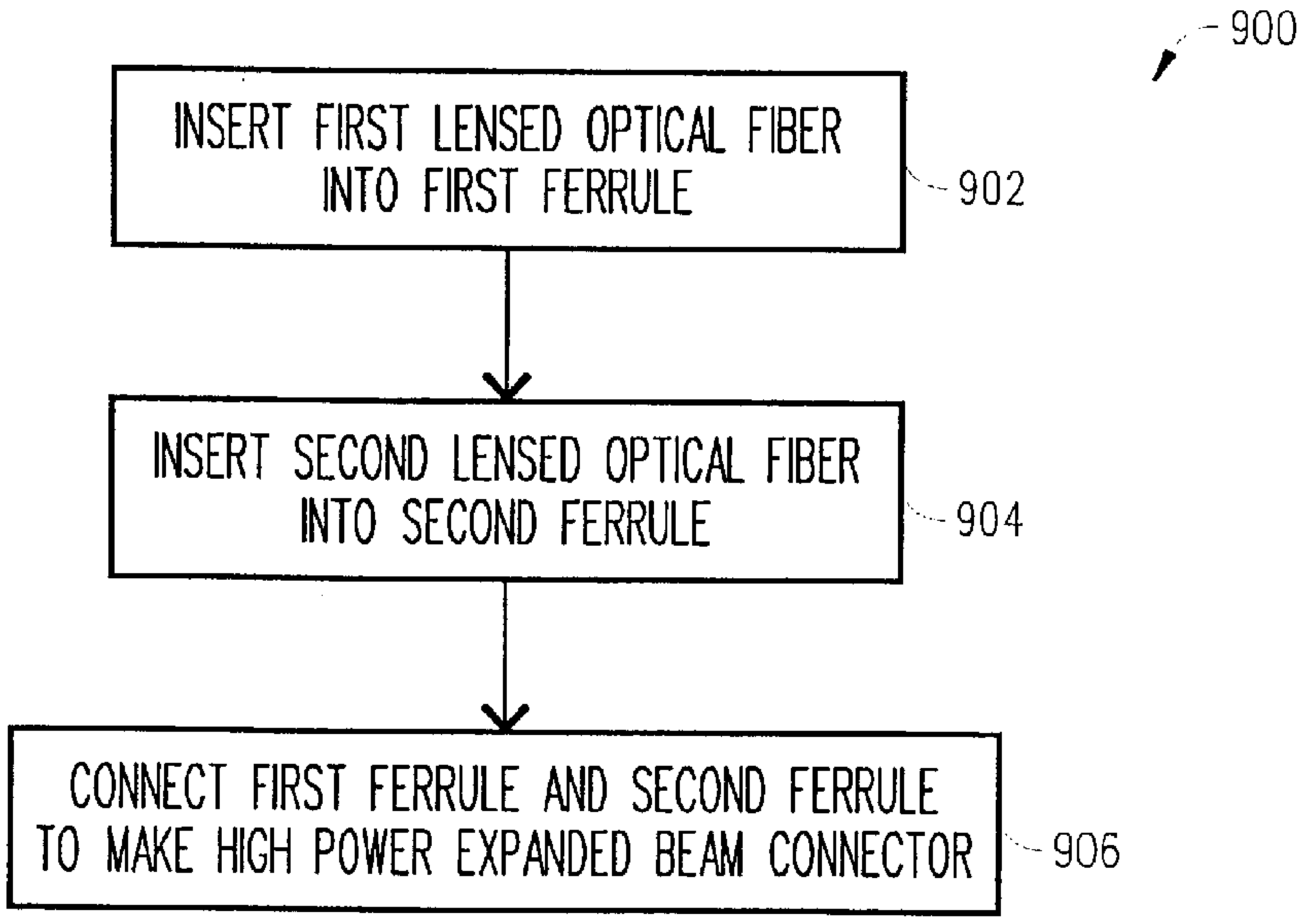

900
INSERT FIRST LENSED OPTICAL FIBER INTO FIRST FERRULE
902
INSERT SECOND LENSED OPTICAL FIBER INTO SECOND FERRULE
904
CONNECT FIRST FERRULE AND SECOND FERRULE TO MAKE HIGH POWER EXPANDED BEAM CONNECTOR
906

FIG. 9

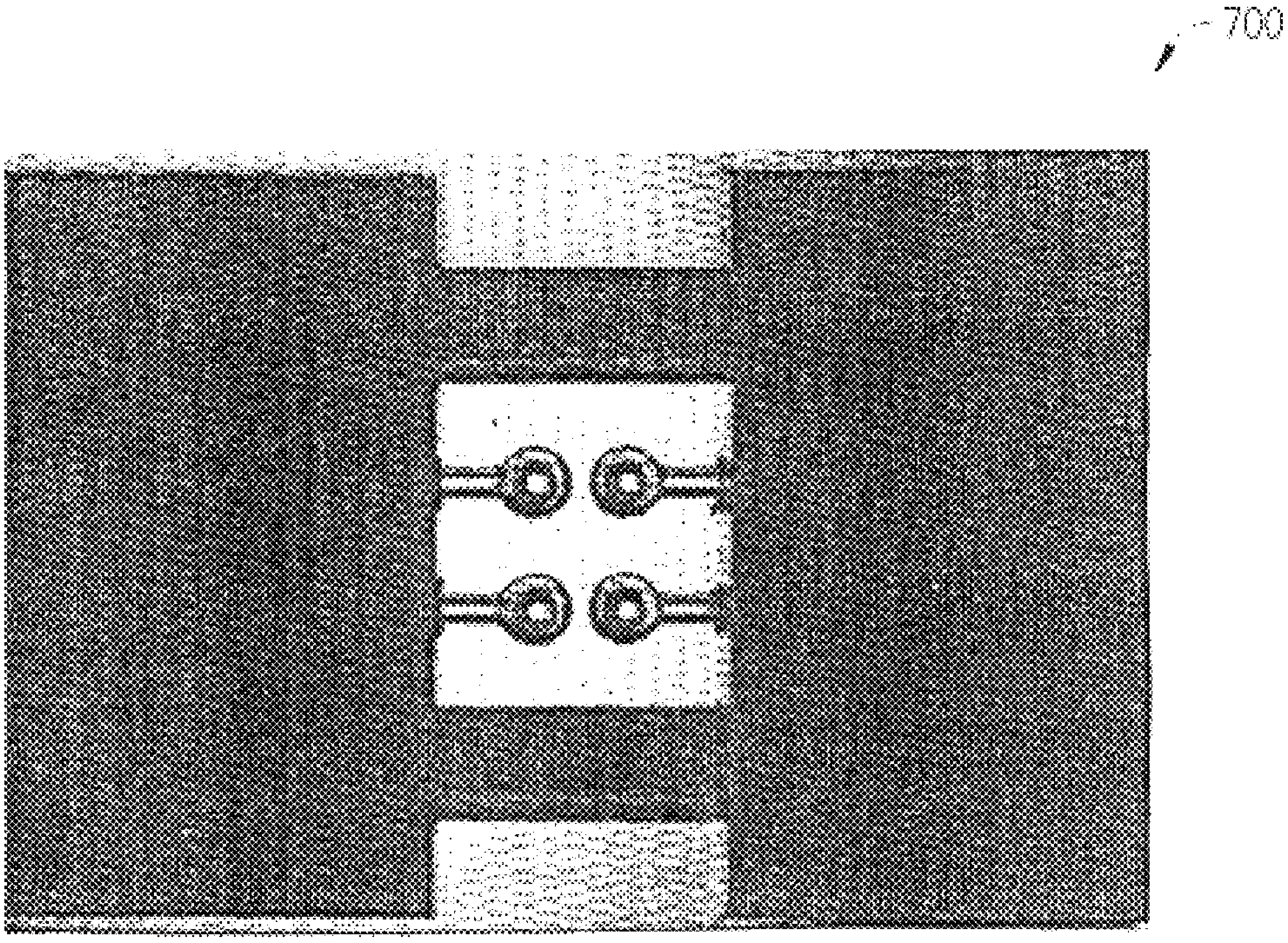

700

FIG. 10

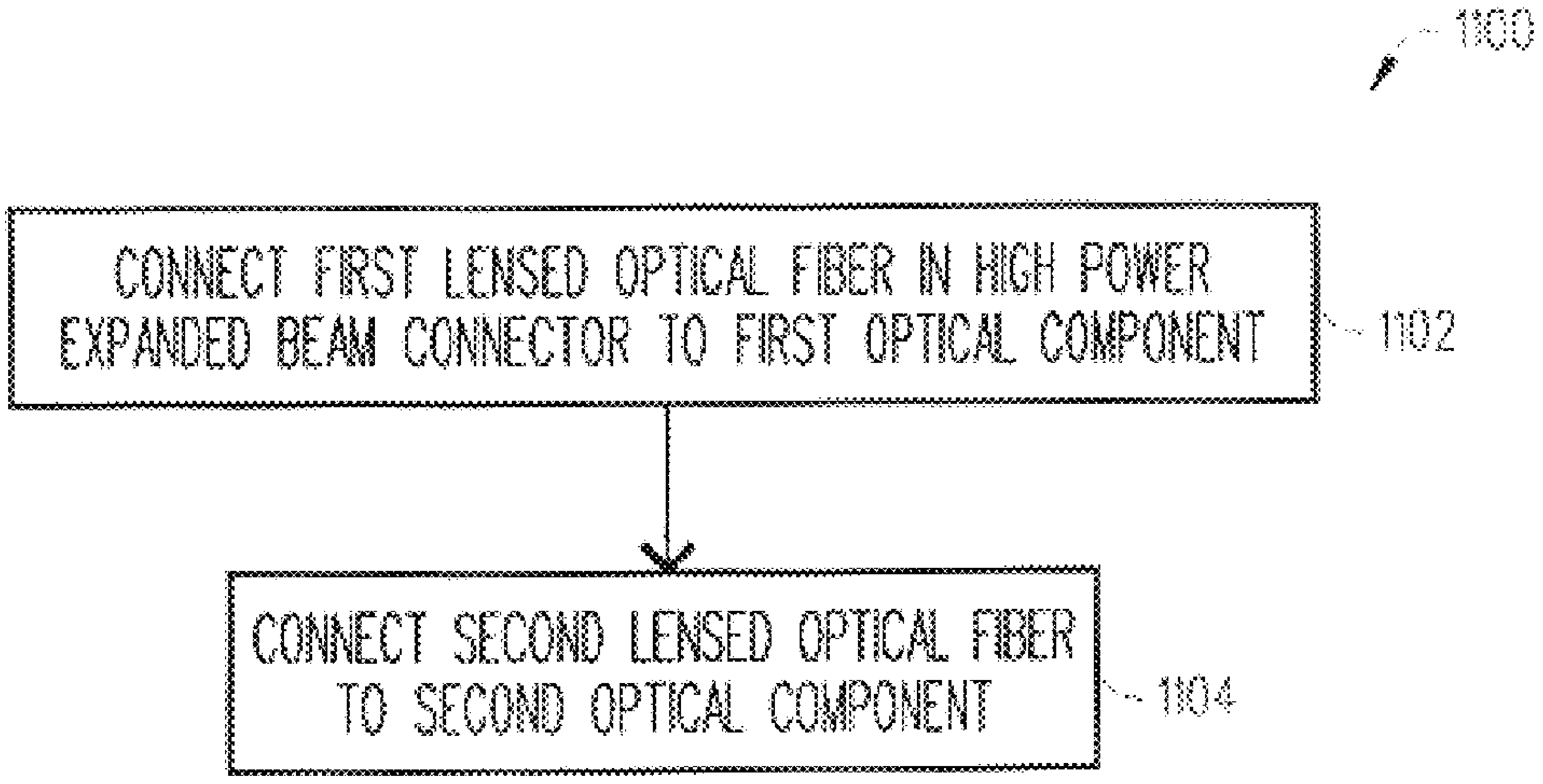

1100
CONNECT FIRST LENSED OPTICAL FIBER IN HIGH POWER EXPANDED BEAM CONNECTOR TO FIRST OPTICAL COMPONENT
1102
CONNECT SECOND LENSED OPTICAL FIBER TO SECOND OPTICAL COMPONENT
1104

FIG. 11

HIGH POWER EXPANDED BEAM CONNECTOR AND METHODS FOR USING AND MAKING THE HIGH POWER EXPANDED BEAM CONNECTOR

CLAIMING BENEFIT OF PRIOR FILED PROVISIONAL APPLICATION

This application claims the benefit of U.S. Provisional Application Ser. No. 60/303,610, filed on Jul. 5, 2001 and entitled "Expanded Beam Connector for High Power Application" which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates in general to optical connectors and, in particular, to a high power expanded beam connector that can be used to couple optical fibers in high power applications.

2. Description of Related Art

Manufacturers of optical connectors have been trying to design an optical connector that can be used in high power applications to couple optical fibers. Traditional butt-joint connectors are not considered suitable for high power applications because any particle contamination from the cleaning process or any glue from the packaging which is left at or near the joint could cause catastrophic failure. Accordingly, there is a need for a high power optical connector that addresses the aforementioned problem of the traditional butt-joint connector. This need and other needs are addressed by the high power expanded beam connector and methods of the present invention.

BRIEF DESCRIPTION OF THE INVENTION

The present invention includes a high power expanded beam connector that can be used to couple optical fibers in high power applications. Basically, the high power expanded beam connector includes a first lensed optical fiber that is optically coupled to a second lensed optical fiber but physically separated from the second lensed optical fiber. The first lensed optical fiber is capable of expanding a light beam traveling therein and outputting a collimated light beam. The second lensed optical fiber is capable of receiving the collimated light beam and focusing the received light beam such that the light beam travels from the first lensed optical fiber to the second lensed optical fiber. In a similar manner, the high power expanded beam connector can transmit a light beam from the second lensed optical fiber to the first lensed optical fiber. The present invention also includes methods for making and using the high power expanded beam connector.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIG. **1** is a block diagram showing an exploded view of a high power expanded beam connector in accordance with the present invention;

FIG. **2** is a perspective view of the bottom portions of two exemplary ferrules used to support the lensed optical fibers of the high power expanded beam connector shown in FIG. **1**;

FIG. **3** is a block diagram illustrating various geometrical dimensions of two lensed optical fibers;

FIG. **4** is a micrograph of a lensed optical fiber that can be incorporated within the high power expanded beam connector shown in FIG. **1**;

FIG. **5** is a graph showing the effect of thermal core broadening on lensed optical fibers that have silica plano convex lens and borosilicate plano convex lens;

FIGS. **6**A and **6**B are graphs showing the relationship between different lens geometries and different distances to beam waste for signal mode fibers (e.g., Corning's SMF-28™) at λ=1550 nm;

FIG. **7** is a graph showing calculated back reflections or return losses of different lensed optical fibers;

FIGS. **8**A–**8**C are graphs showing various tolerances (e.g., lateral offset, angular offset, longitudinal displacement) associated with the high power expanded beam connector shown in FIG. **1**;

FIG. **9** is a flowchart illustrating the steps of a preferred method for making the high power expanded beam connector shown in FIG. **1**;

FIG. **10** is a photograph showing a cross-sectional side view of an exemplary high power expanded beam connector including two pairs of lensed optical fibers in accordance with the present invention; and

FIG. **11** is a flowchart illustrating the steps of a preferred method for using the high power expanded beam connector shown in FIG. **1**.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIGS. **1**–**11**, there is disclosed a preferred embodiment of a high power expanded beam connector **100** and preferred methods **900** and **1100** for making and using the high power expanded beam connector **100**. Although the high power expanded beam connector **100** is described as optically connecting only one pair of fibers, it should be understood that the high power expanded beam connector **100** can be used to connect one or more pairs of fibers (see FIG. **10**). Accordingly, the high power expanded beam connector **100** and the preferred methods **900** and **1100** should not be construed in such a limited manner.

Basically, the high power expanded beam connector **100** includes a first lensed optical fiber **104** that is optically coupled to a second lensed optical fiber **106** but physically separated from the second lensed optical fiber **106**. The first lensed optical fiber **104** is capable of expanding (diverging) a light beam **302** traveling therein and outputting a collimated light beam **302** (FIG. **3** shows the light beam **302**—which is collimated when between lensed fibers **104** and **106**). The second lensed optical fiber **106** is capable of receiving the collimated light beam **302** and focusing (converging) the received light beam **302** such that the light beam **302** travels from the first lensed optical fiber **104** to the second lensed optical fiber **106**. In a similar manner, the high power expanded beam connector **100** can transmit a light beam **302** from the second lensed optical fiber **106** to the first lensed optical fiber **104**.

Referring to FIG. **1**, there is a block diagram showing an exploded view of the high power expanded beam connector **100** that can be used to optically connect one or more pairs of fibers **101** (e.g., single mode fibers such as Corning's SMF-28™). The high power expanded beam connector **100** can be used with a wide variety of optical amplifiers including, for example, Raman amplifiers which operate at or above 100 mW. As described above, traditional butt-joint connectors are not considered suitable in high power applications because any particle contamination from the cleaning process or any glue from the packaging which is left at or near the joint could cause catastrophic failure. However, the high power expanded beam connector **100** is well suited for high power applications (e.g., $\geqq 100$ mW) because the beam is expanded from an effective area of about 90 μm^2 (λ=1550 nm, Corning's SMF-28™) to more than 20,000 μm^2 at the convex surface of the lens **116** and **118**. In other words, the high power expanded beam connector **100** is not as sensitive to contaminates like dirt and glue because of the larger beam area which implies a much lower power density. As such, the lack of physical contact between the lensed optical fibers **104** and **106** improves power handling and minimizes the impact of contaminates like dirt and glue.

As illustrated in FIG. **1**, the high power expanded beam connector **100** includes a package **102** that supports the first lensed optical fiber **104** and the second lensed optical fiber **106**. In particular, the package **102** supports and aligns the first lensed optical fiber **104** and the second lensed optical fiber **106** such that they face each other and are separated by a predetermined distance from each other to minimize insertion loss.

The package **102** includes a first ferrule **108**, a second ferrule **110** and a mating alignment fixture **112**. The first ferrule **108** supports and protects the first lensed optical fiber **104**. Likewise, the second ferrule **110** supports and protects the second lensed optical fiber **106**. The mating alignment fixture **112** along with one or more alignment pins **114** (two shown) are capable of aligning and holding the first ferrule **108** and the second ferrule **110** in place such that the first lensed optical fiber **104** is separated a predetermined distance from the second lensed optical fiber **106**. The alignment pins **114** also help to align the two lensed optical fibers **104** and **106**.

The first ferrule **108** and the second ferrule **110** can be made from many different materials and can take many different forms. One such form is shown in FIG. **1**, where convex lens **116** and **118** of the first lensed optical fiber **104** and the second lensed optical fiber **106** extend from the first ferrule **108** and the second ferrule **110**, respectively. Another such form is shown in FIG. **2**, where the convex lens **116** and **118** of the first lensed optical fiber **104** and the second lensed optical fiber **106** do not extend from the first ferrule **108** and the second ferrule **110**, respectively. Instead, the first ferrule **108** and the second ferrule **110** are each made of a top piece (not shown) and a bottom piece **202***a* and **202***b* that are epoxied together around the first lensed optical fiber **104** and the second lensed optical fiber **106**. In the second example, the first ferrule **108** and the second ferrule **110** can be butted against one another and still maintain the predetermined distance between the first lensed optical fiber **104** and the second lensed optical fiber **106**.

In operation, the high power expanded beam connector **100** includes the first lensed optical fiber **104** which is capable of expanding a light beam **302** traveling therein and outputting a collimated light beam **302** (FIG. **3** shows light beam **302**). The second lensed optical fiber **106** is capable of receiving the collimated light beam **302** and focusing the received light beam **302** such that the light beam **302** travels from the first lensed optical fiber **104** to the second lensed optical fiber **106**. In a similar manner, the high power expanded beam connector **100** can also transmit a light beam **302** from the second lensed optical fiber **106** to the first lensed optical fiber **104**. Details about the first lensed optical fiber **104** and the second lensed optical fiber **106** are provided below with respect to FIGS. **3**–**8**.

Referring to FIG. **3**, there is a block diagram illustrating various geometrical dimensions of two lensed optical fibers **104** and **106**. The geometrical dimensions of the lensed optical fibers **104** and **106** dictate the distance the first lensed optical fiber **104** is to be separated from the second lensed optical fiber **106**. It should be understood that the lens **116** and **118** are perfect collimators when:

$$T=R_c*(n/n-1)+\Phi$$

where T=thickness of lens **116** and **118**;

R_c=radius curvature of lens **116** and **118**;

n=index of refraction of lens **116** and **118**.

Φ=phase shift

For example at 1550 m and using silica (n=1.444), the lens **116** and **118** are a perfect collimators when T/R_c=3.25. In practice, the thickness of spherical lens **116** and **118** needs to be increased by the diffractive focal shift because the lensed optical fibers **104** and **106** are not a point source and the spherical lens portion **116** and **118** are very small so the diffraction effects are large. Thus, in practice the T/R_c ratio is greater than 3.25.

An exemplary high power expanded beam connector **100** could have a geometry with a beam waist of 50 to 100 microns away from each surface of the lens **116** and **118**, thus giving the lens **116** to lens **118** separation of 100–200 microns. Such a high power expanded beam connector **100** would have lens **116** and **118** with a 227 micron radius of curvature (R_c), a 765 micron thickness (T) and mode field diameters (MFDs) at the beam waist of 85 microns. This design of the spherical lens portion **116** and **118** allows for a high tolerance to lateral and axial misalignment in the high power expanded beam connector **100** (see FIGS. **8A**–**8C**).

Referring to FIG. **4**, there is a micrograph of an exemplary lensed optical fiber **104** and **106** that can be used in the present invention. The glass lens **400** (e.g., plano-convex collimating lens, lens member) as shown is made from glass that is transparent at the wavelength of interest and fusion spliced to an optical fiber **101**. The glass lens **400** has a coefficient of thermal expansion (CTE) that matches or closely matches the CTE of the optical fiber **101**. Essentially, the glass lens **400** has a thickness "T" and a radius of curvature "R_c" (see FIG. **3**). More specifically, the glass lens **400** includes a throat portion **402** and a spherical lens portion **116** and **118**. The lensed optical fibers **104** and **106** can be made by splicing one end of the throat portion **402** to the optical cable **101**. Then a fusion splicer with a tungsten filament can be used to form the convex lens **116** and **118** at the other end of the throat portion **402**. A more detailed discussion about the glass lens **400** is provided in Corning's U.S. patent application Ser. No. 09/812,108 the contents of which are incorporated herein by reference.

In the preferred embodiment, the lensed optical fibers **104** and **106** and in particular the lens **116** and **118** are made of borosilicate glass. The spherical lens portion **116** and **118** that are made of borosilicate glass do not suffer from birefringence, whereas spherical lens that are made from silica are birefringent which contributes to polarization dependant losses. Moreover, the performance of the high power expanded beam connector **100** can be enhanced when the lens **116** and **118** are made from borosilicate glass. Because, the fusion splicing of the fibers **101** to a borosilicate glass causes thermal core broadening which enlarges the mode field diameter (MFD) and increases the tolerances for lateral misalignment of the lensed optical fibers **104** and **106**. In addition, the production process of the lens **116** and **118** is much more reproducible when borosilicate glass is used instead of silica.

For a more a detailed comparison between the lensed optical fibers **104** and **106** made from borosilicate glass and the lensed optical fibers **104** and **106** made from silica see FIG. **5**. In particular, the effect of thermal core broadening can be seen with reference to FIG. **5**. Data points represent measured MFD in x and y directions for a silica and borosilicate lens attached to Corning's SMF-28. The solid lines represent the fit of a gaussian beam model. The data indicates that the core of Corning's SMF-28™ has broadened to about 13.6 μm from nominal fiber mode field of 10.4 μm.

Referring to FIGS. **6**A and **6**B, there are illustrated graphs showing the relationship between different geometries of lens **104** and **106** and different distances to beam waste for signal mode fibers (e.g., Corning's SMF-28™) at λ=1550 nm. This type of information helps one to determine the desired spacing between the spherical lens portion **116** and **118** in the high power expanded beam connector **100**.

Referring back to FIGS. **1** and **3**, the spherical lens portion **116** and **118** can also be covered with an antireflection (AR) coating (not shown) which functions to prevent the light beam **302** from reflecting back into fiber **101** when the light beam **302** hits the surface of the lens **116** and **118**. In an experiment conducted by the inventors, the excess loss or coupling efficiency of AR coated and uncoated lensed optical fibers **104** and **106** was measured by facing the lens **116** and **118** towards each other and aligning the lens **116** and **118** to get the maximum power reading. It should be noted that the typical coupling efficiency of antireflection coated lensed optical fibers **104** and **106** is <0.2 dB/pair. During the experiment, one lens **116** was connected to a broadband source and the other lens **118** was connected to a detector. Table 1 shows the return loss measurements of AR coated and uncoated lens **116** and **118**:

TABLE 1

Lens no.	1542 nm return loss (-dB)	Glass	AR coating
593	63.6	OVD silica	Yes
594	68.7	OVD silica	Yes
597	66.0	HPFS	Yes
598	64.8	HPFS	Yes
620	57.5	Borosilicate	Yes
621	62.1	Borosilicate	Yes
547	41.0	OVD silica	No
548	41.1	OVD silica	No
503	41.2	HPFS	No
504	40.9	HPFS	No
1253	40.1	Borosilicate	No
1254	40.9	Borosilicate	No

As can be seen from Table **1**, the return loss measurements at 1542 nm shown that the average loss of AR coated lens **116** and **118** is below −60 dB and uncoated lens **116** and **118** is approximately −40 dB. For a test sample of 6 AR coated lens **116** and **118**, the return loss measurements ranged between −57 and −69 dB where only one lens had a return loss measurement that was greater than −60 dB. These measurements were performed on relatively small lens **116** and **118** with an R_c~225 microns and T~800 microns. A more detailed analysis of return loss measurements (back reflection loss) is provided below with respect to FIG. **7**.

Referring to FIG. **7**, there is illustrated a graph showing calculated back reflections or return losses of different lensed optical fibers **104** and **106**. Basically, it can be seen that for AR coated lenses **104** and **106** with a coating that has 0.25% reflectivity, it is possible to achieve back reflection greater than 55 dB. Lenses **104** and **106** with a smaller radius of curvature will have a lower back reflection, at the same lens thickness. This adds flexibility to the design of the lens **104** and **106** which allows one to maximize the back reflection for a desired lens-to-lens separation.

Referring to FIGS. **8**A–**8**C, there are graphs showing various tolerances (e.g., lateral offset, angular offset, longitudinal displacement) associated with the high power expanded beam connector **100**. In particular, the graphs show the effect of lateral, angular and longitudinal misalignment on loss in the high power expanded beam connector **100** with lensed optical fibers **104** and **106** (MFD=62 microns) and in the traditional butt-joint connectors of single mode fibers such as SMF-28™ (MFD=10.4), NZ-DSF with large area (MFD=9.6 microns) and NZ-DSF (MFD=8.4 microns). In FIGS. **8**A and **8**C, it can be seen that lateral and longitudinal tolerances are much better in the high power expanded beam connector **100** (e.g., lensed optical fibers **104** and **106**) compared to traditional butt-joint connectors. However, in FIG. **8**B it can be seen that the tolerance to angular misalignment is much worse in the high power expanded beam connector **100**. The smaller tolerance to angular misalignment is due to the larger MFD of the high power expanded beam connector **100**. As such, the mechanical design of the high power expanded beam connector **100** should not allow for tilting. Moreover, it is preferred to have a short working distance (e.g., lens-to-lens separation) because angular misalignment induces less lateral misalignment if the working distance is short.

Referring to FIG. **9**, there is a flowchart illustrating the steps of a preferred method **900** for making the high power expanded beam connector **100**. To make the high power expanded beam connector **100**, the first lensed optical fiber **104** is inserted (step **902**) into the first ferrule **108**. Likewise, the second lensed optical fiber **106** is inserted (step **904**) into the second ferrule **110**. In the preferred embodiment, the first lensed optical fiber **104** and the second lensed optical fiber **106** would be coated with an antireflection coating to reduce return loss (backreflection).

Thereafter, the first ferrule **108** is connected (step **906**) to the second ferrule **110**. This can be accomplished in several ways. For example, the mating alignment fixture **112** as shown in FIG. **1** along with one or more alignment pins **114** (two shown) can be used to align and hold the first ferrule **108** and the second ferrule **110**. Alternatively, the first ferrule **108** and the second ferrule **110** can be connected to each other using, for example, a keyed bayonet coupling or a coupling receptacle. As a result, the first ferrule **108** and the second ferrule **110** are secured to one another in a manner such that the first lensed optical fiber **104** is aligned and separated a predetermined distance from the second lensed optical fiber **106**.

After connecting the first ferrule **108** to the second ferrule **110**, the high power expanded beam connector **100** and in particular the first lensed optical fiber **104** is capable of expanding a light beam **302** traveling therein and outputting a collimated light beam **302** towards the second lensed optical fiber **106**. The second lensed optical fiber **106** upon receiving the collimated light beam **302** focuses the received light beam **302** such that the light beam **302** travels from the first lensed optical fiber **104** to the second lensed optical fiber **106**. In a similar manner, the high power expanded beam connector **100** can also transmit a light beam **302** from the second lensed optical fiber **106** to the first lensed optical fiber **104**.

Referring to FIG. **10**, there is a photograph showing a cross-sectional side view of an exemplary high power expanded beam connector **100** including two pairs of lensed optical fibers in accordance with the present invention.

Referring to FIG. **11**, there is a flowchart illustrating the steps of a preferred method **1100** for using the high power expanded beam connector **100**. Essentially, the first lensed optical fiber **104** of the high power expanded beam connector **100** is connected (step **1102**) to a first optical component (e.g., amplifier). Likewise, the second lensed optical fiber **106** of the high power expanded beam connector **100** is connected (step **1104**) to a second optical component (e.g., amplifier).

Since, the high power expanded beam connector **100** is already assembled. The first lensed optical fiber **104** is capable of expanding a light beam **302** traveling therein and outputting a collimated light beam **302** towards the second lensed optical fiber **106**. The second lensed optical fiber **106** upon receiving the collimated light beam **302** focuses the received light beam **302** such that the light beam **302** travels from the first lensed optical fiber **104** to the second lensed optical fiber **106**. In a similar manner, the high power expanded beam connector **100** can transmit a light beam **302** from the second lensed optical fiber **106** to the first lensed optical fiber **104**.

Although only one embodiment of the present invention have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it should be understood that the invention is not limited to the embodiment disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the spirit of the invention as set forth and defined by the following claims.

What is claimed is:

1. A high power expanded beam connector comprising:

a first lensed optical fiber; and

a second lensed optical fiber optically coupled to said first lensed optical fiber but physically separated a predetermined distance from said first lensed optical fiber, wherein said first lensed optical fiber and said second lensed optical fiber each include an optical fiber that was fusion spliced to a plano-convex borosilicate lens that includes a throat portion and a spherical lens portion, wherein the fusion splicing of the optical fibers to the piano-convex borosilicate lenses enlarges the mode field diameters of said first and second lensed optical fibers which increases the tolerance for lateral misalignment between said first and second lensed optical fibers.

2. The high power expanded beam connector of claim **1**, further comprising a package capable of supporting said first lensed optical fiber and said second lensed optical fiber.

3. The high power expanded beam connector of claim **2**, wherein said package further includes:

a first ferrule capable of supporting said first lensed optical fiber;

a second ferrule capable of supporting said second lensed optical fiber; and

a mating alignment fixture capable of aligning and holding said first ferrule and said second ferrule such that said first lensed optical fiber is separated the predetermined distance from said second lensed optical fiber.

4. The high power expanded beam connector of claim **1**, wherein the throat portions and the spherical lens portions each have a geometry that dictates the predetermined distance said first lensed optical fiber is to be physically separated from said second lensed optical fiber.

5. The high power expanded beam connector of claim **1**, wherein said first lensed optical fiber and said second lensed optical fiber are capable of being used in a high power application operating at or greater than 100 mW because a light beam is expanded from an area in the range of 90 μm^2 to more than 20,000 μm^2 at one of the spherical lens portions of the plano-convex borosilicate lenses.

6. The high power expanded beam connector of claim **1**, wherein said high power expanded beam connector is an arrayed high power expanded beam connector.

7. The high power expanded beam connector of claim **1**, wherein said expanded beam connector is associated with an optical amplifier.

8. The high power expanded beam connector of claim **1**, wherein said first lensed optical fiber is capable of outputting a collimated light beam and said second lensed optical fiber is capable of receiving the collimated light beam because each of the spherical lens portions have a geometry and index of refraction in accordance with the following equation:

$$T=R_c*(n/n-1)+\Phi$$

where T=thickness of the respective spherical lens portion

R_c=radius curvature of the respective spherical lens portion

n=index of refraction of the respective spherical lens portion

Φ=phase shift

and wherein said thickness of each spherical lens portion is then increased by at least one diffractive focal shift to take into account the particular geometries of said first and second lensed optical fibers.

9. A high power expanded beam connector used in high power applications operating at or greater than 100 mW, said high power expanded beam connector comprising:

a first lensed optical fiber including a first optical fiber that was fusion spliced to a first plano-convex borosilicate lens that includes a throat portion and a spherical lens portion, wherein said first lensed optical fiber is capable of expanding a light beam and outputting a collimated light beam;

a second lensed optical fiber including a second optical fiber that was fusion spliced to a second piano-convex borosilicate lens that includes a throat portion and a spherical lens portion, wherein said second lensed optical fiber is separated a predetermined distance from said first lensed optical fiber, wherein said second lensed optical fiber is capable of receiving the collimated light beam and focusing the received light beam such that the light beam travels from said first lensed optical fiber to said second lensed optical fiber, wherein the fusion splicing of the first and second optical fibers to the first and second plano-convex borosilicate lenses enlarges the mode field diameters of said first and second lensed optical fibers which increases the tolerance for lateral misalignment between said first and second lensed optical fibers.

10. The high power expanded beam connector of claim **9**, further comprising a package capable of supporting and aligning said first lensed optical fiber and said second lensed optical fiber in a manner such that said first lensed optical fiber and said second lensed optical fiber face each other and are physically separated the predetermined distance.

11. The high power expanded beam connector of claim **9**, wherein the throat portions and the spherical lens portions each have a geometry that dictates the predetermined distance said first lensed optical fiber is to be physically separated from said second lensed optical fiber.

12. The high power expanded beam connector of claim **9**, wherein each spherical lens portion is coated with an anti-reflection coating.

13. The high power expanded beam connector of claim **9**, wherein said high power expanded beam connector includes more than one pair of said first and second lensed optical fibers.

14. The high power expanded beam connector of claim **9**, wherein said high power expanded beam connector is associated with a Raman amplifier.

15. The high power expanded beam connector of claim **9**, wherein said first lensed optical fiber is capable of outputting the collimated light beam and said second lensed optical fiber is capable of receiving the collimated light beam because each of the spherical lens portions have a geometry and index of refraction in accordance with the following equation:

$$T=R_c*(n/n-1)+\Phi$$

where T=thickness of the respective spherical lens portion

R_c=radius curvature of the respective spherical lens portion

n=index of refraction of the respective spherical lens portion

Φ=phase shift

and wherein said thickness of each spherical lens portion is then increased by at least one diffractive focal shift to take into account the particular geometries of said first and second lensed optical fibers.

16. A method for making a high power expanded beam connector, said method comprising the steps of:

inserting a first lensed optical fiber into a first ferrule, wherein said first lensed optical fiber includes a first optical fiber that was fusion spliced to a first plano-convex borosilicate lens that includes a throat portion and a spherical lens portion;

inserting a second lensed optical fiber into a second ferrule, wherein said second lensed optical fiber includes a second optical fiber that was fusion spliced to a second piano-convex borosilicate lens that includes a throat portion and a spherical lens portion; and

securing said first ferrule and said second ferrule such that said first lensed optical fiber and said second lensed optical fiber are aligned and separated a predetermined distance from one another thus enabling said first lensed optical fiber to expand a light beam traveling therein and then to output a collimated light beam towards said second lensed optical fiber which receives the collimated light beam and focuses the received light beam such that the light beam travels from said first lensed optical fiber to said second lensed optical fiber, wherein the fusion splicing of the first and second optical fibers to the first and second piano-convex borosilicate lenses enlarges the mode field diameters of said first and second lensed optical fibers which increases the tolerance for lateral misalignment between said first and second lensed optical fibers.

17. The method of claim **16**, wherein the throat portions and the spherical lens portions each have a geometry that dictates the predetermined distance said first lensed optical fiber is to be physically separated from said second lensed optical fiber.

18. The method of claim **16**, wherein each spherical lens portion is coated with an antireflection coating.

19. The method of claim **16**, wherein said first lensed optical fiber and said second lensed optical fiber are capable of being used in a high power application operating at or greater than 100 mW because the light beam is expanded from an area in the range of 90 μm^2 to more than 20,000 μm^2 at the spherical lens portion of the plano-convex borosilicate lens in the first lensed optical fiber.

20. The method of claim **16**, wherein said first lensed optical fiber is capable of outputting the collimated light beam and said second lensed optical fiber is capable of receiving the collimated light beam because each of the spherical lens portions have a geometry and index of refraction in accordance with the following equation:

$$T=R_c*(n/n-1)+\Phi$$

where T=thickness of the respective spherical lens portion

R_c=radius curvature of the respective spherical lens portion

n=index of refraction of the respective spherical lens portion

Φ=phase shift

and wherein said thickness of each spherical lens portion is then increased by at least one diffractive focal shift to take into account the particular geometries of said first and second lensed optical fibers.

21. A method for using a high power expanded beam connector, said method comprising the steps of:

connecting a first lensed optical fiber of said expanded beam connector to a first optical component, wherein said first lensed optical fiber includes a first optical fiber that was fusion spliced to a first plano-convex borosilicate lens that includes a throat portion and a spherical lens portion; and

connecting a second lensed optical fiber of said expanded beam connector to a second optical component, wherein said second lensed optical fiber includes a second optical fiber that was fusion spliced to a second plano-convex borosilicate lens that includes a throat portion and a spherical lens portion, and wherein said first lensed optical fiber and said second lensed optical fiber are aligned and separated a predetermined distance from one another thus enabling said first lensed optical fiber to expand a light beam traveling therein and to output a collimated light beam towards said second lensed optical fiber which receives the collimated light beam and focuses the received light beam such that the light beam travels from said first optical component to said second optical component, wherein the fusion splicing of the first and second optical fibers to the first and second piano-convex borosilicate lenses enlarges the mode field diameters of said first and second lensed optical fibers which increases the tolerance for lateral misalignment between said first and second lensed optical fibers.

22. The method of claim **21**, wherein the throat portions and the spherical lens portions each have a geometry that dictates the predetermined distance said first lensed optical fiber is to be physically separated from said second lensed optical fiber.

23. The method of claim **21**, wherein each spherical lens portion is coated with an antireflection coating.

24. The method of claim **21**, wherein said first lensed optical fiber and said second lensed optical fiber are capable of being used in a high power application operating at or greater than 100 mW because the light beam is expanded from an area in the range of 90 μm^2 to more than 20,000 μm^2 at the spherical lens portion of the piano-convex borosilicate lens in the first lensed optical fiber.

25. The method of claim **21**, wherein said first lensed optical fiber is capable of outputting the collimated light beam and said second lensed optical fiber is capable of receiving the collimated light beam because each of the spherical lens portions have a geometry and index of refraction in accordance with the following equation:

$$T=R_c*(n/n-1)+\Phi$$

where T=thickness of the respective spherical lens portion

R_c=radius curvature of the respective spherical lens portion

n=index of refraction of the respective spherical lens portion

Φ=phase shift

and wherein said thickness of each spherical lens portion is then increased by at least one diffractive focal shift to take into account the particular geometries of said first and second lensed optical fibers.

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